# Some Incomplete Thoughts on Dose Conversion Coefficients

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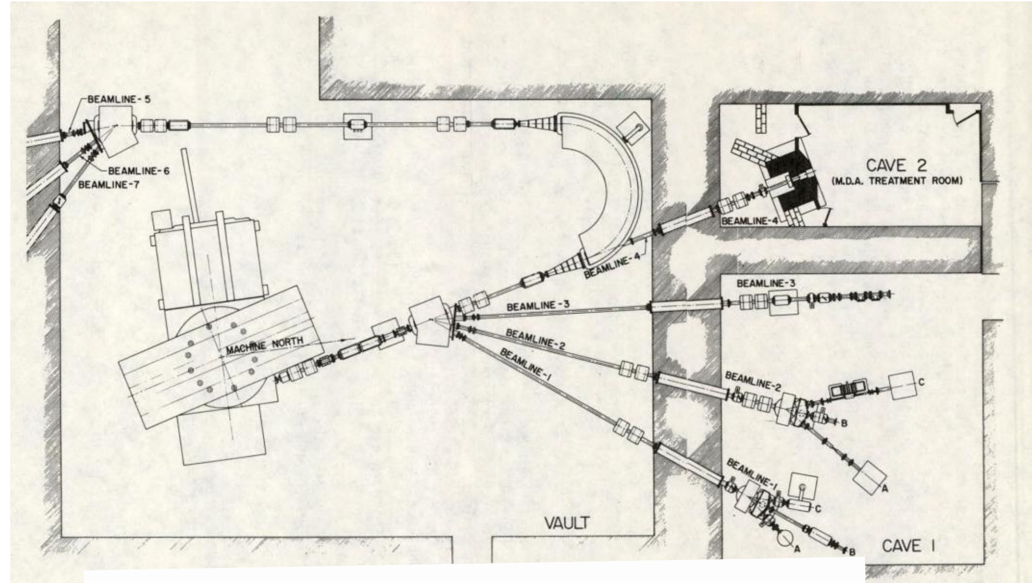
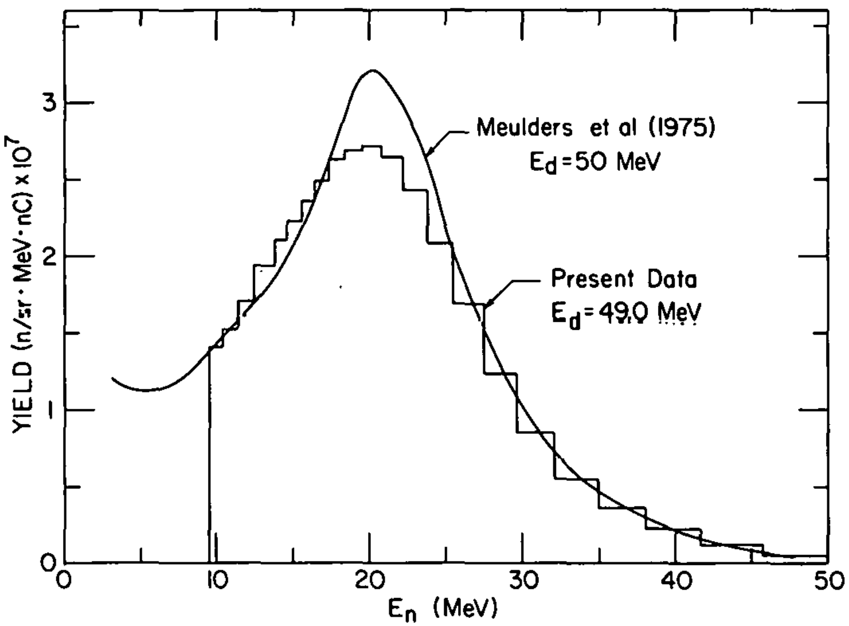
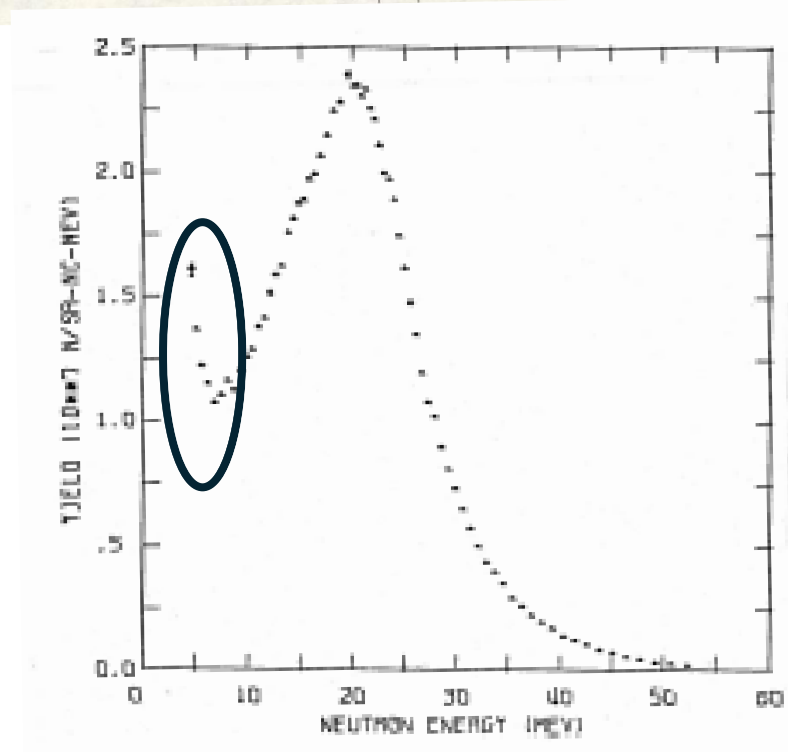
# Outline

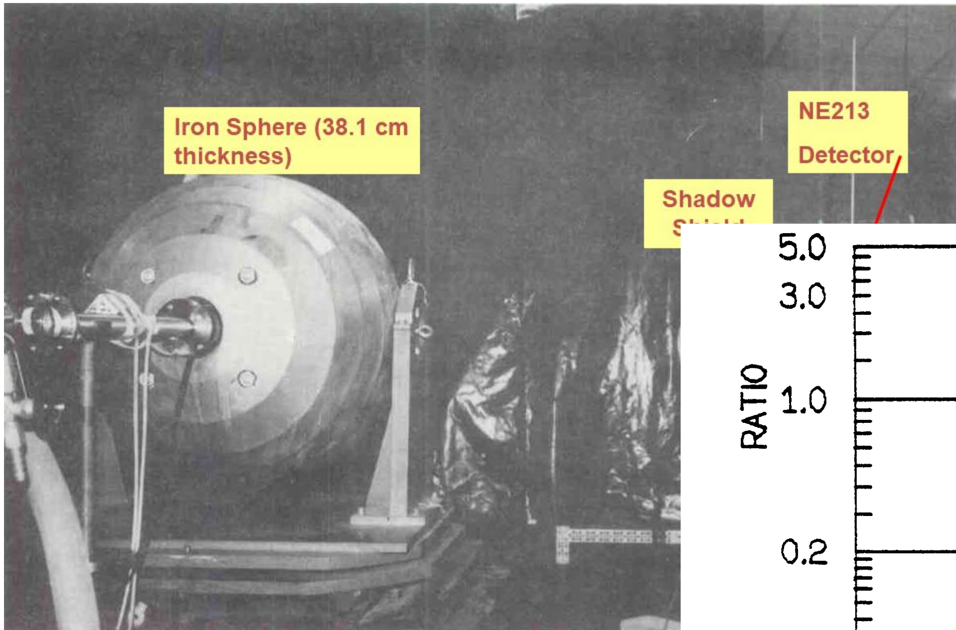
- How did I get into working on dose coefficients?
- Some historical development of dose conversion coefficients (or if you are old dose conversion factors)
- Development in recent years (largely operational quantities)
- Current status

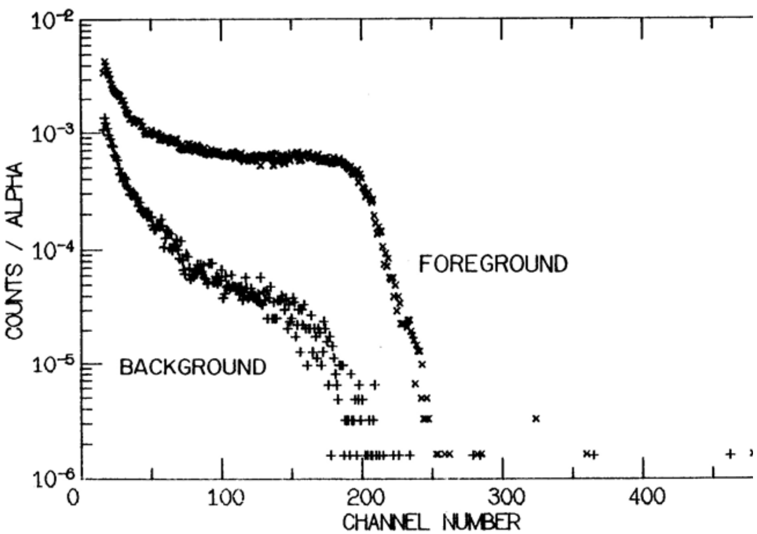
*Symposium on Neutron Cross-Sections 10-40 MeV*, BNL-NCS-50681

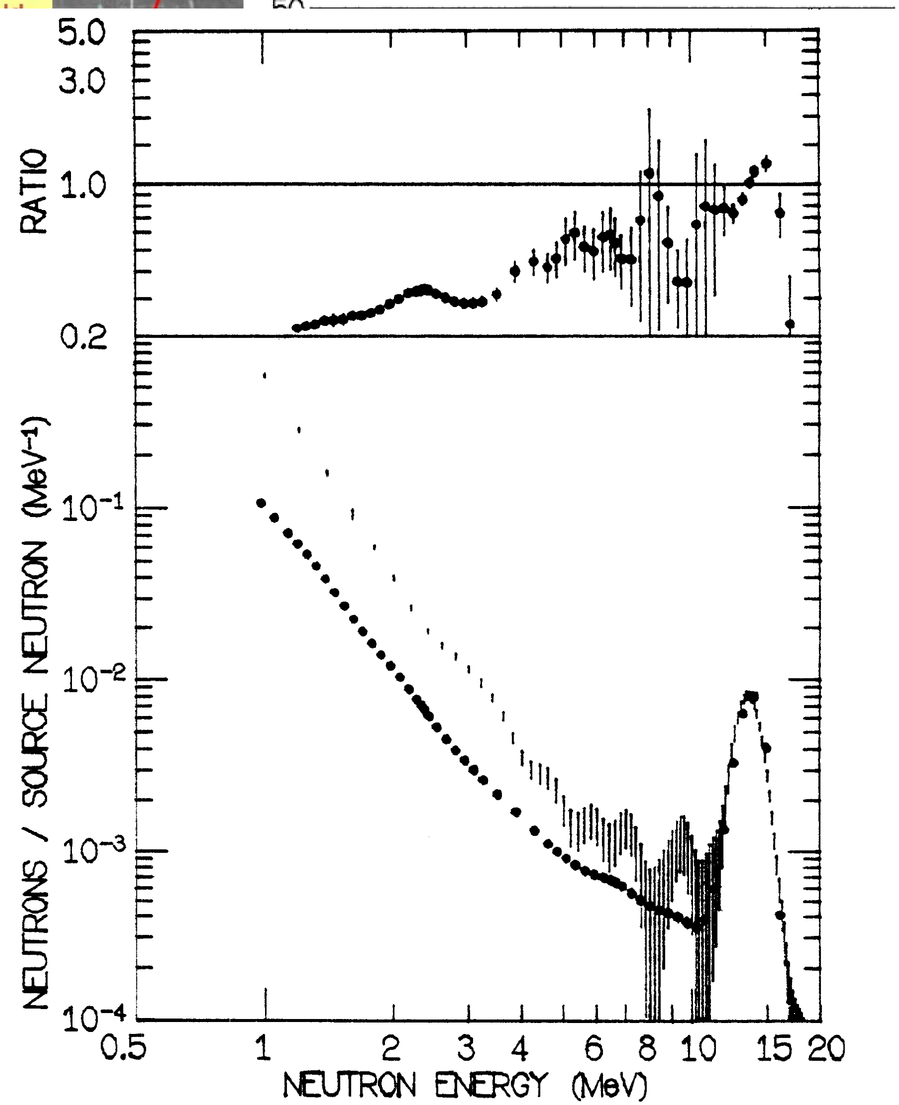


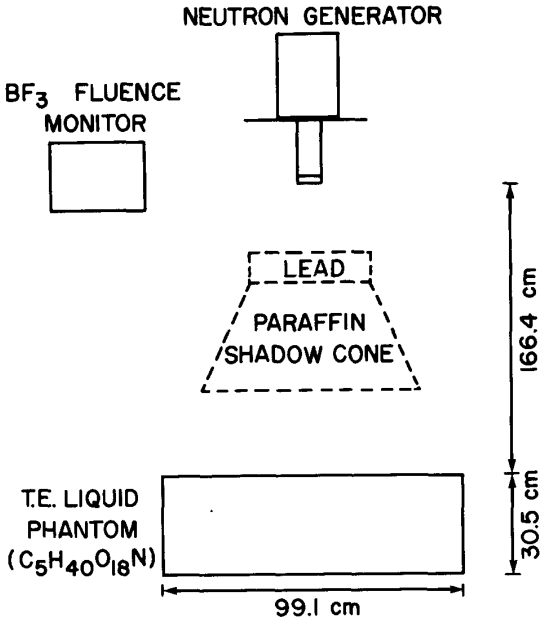



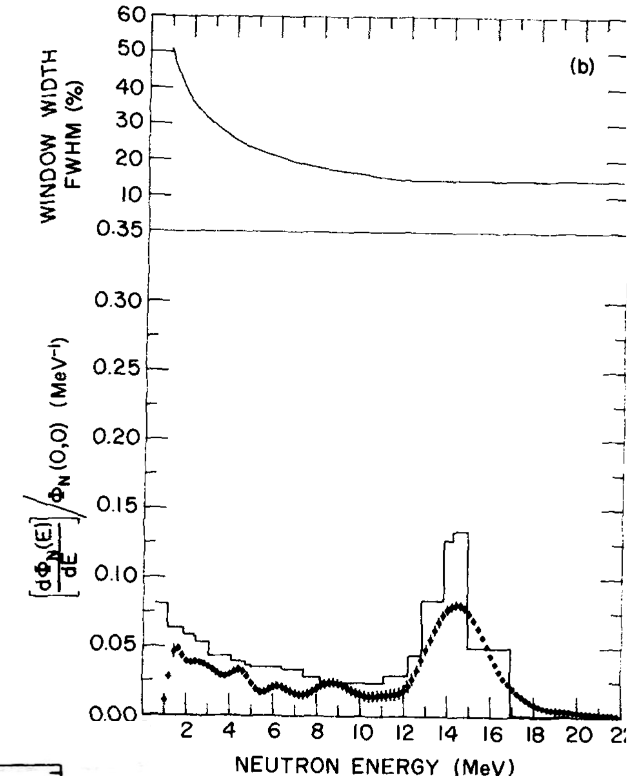



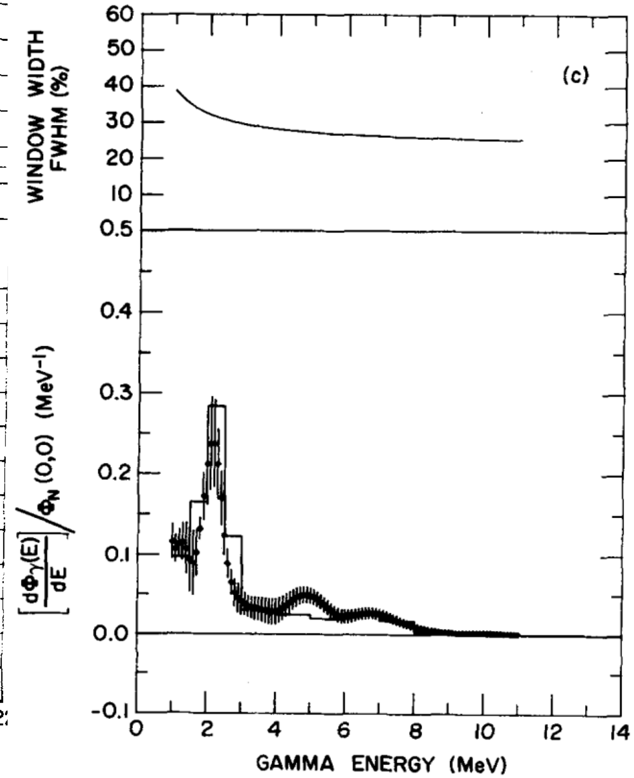

Iron Sphere (38.1 cm thickness)
NE213 Detector
Shadow


COUNTS / ALPHA
FOREGROUND
BACKGROUND
CHANNEL NUMBER

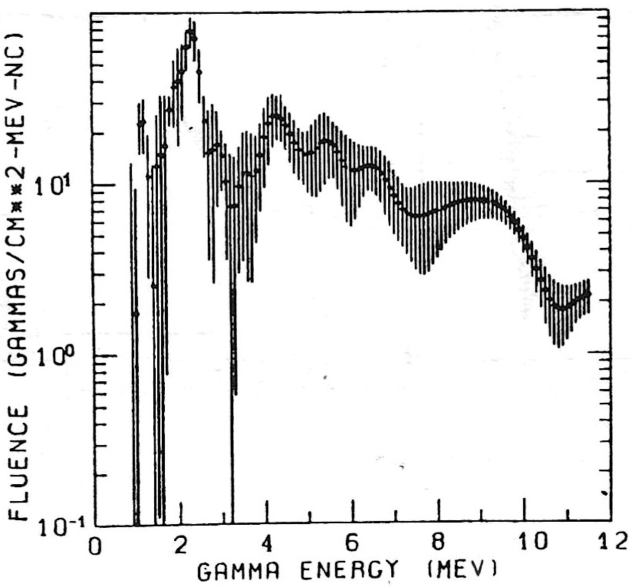

RATIO
NEUTRONS / SOURCE NEUTRON (MeV-1)
NEUTRON ENERGY (MeV)




Medical Physics 10, 66 (1983); doi: 10.1118/1.595377




<u>Proceedings: Fourth Symposium on Neutron Dosimetry</u>, June 1-5, 1981, Neuherberg/Munchen, Federal Republic of Germany, EUR 7448en

# Concept of Radiation Response Function

$$R = \int_0^{\infty} \int_{4\pi} \int_{V} \boldsymbol{\mathfrak{R}\left(\overrightarrow{r_d}, E, \widehat{\Omega}\right)} \cdot \Phi\left(\overrightarrow{r_d}, E, \widehat{\Omega}\right) dV\, d\Omega\, dE$$

- *R* = any dosimetric or instrument response by a target to the fluence of ionizing radiation.
- The response occurs over a sensitive volume which may exhibit directional dependence.
- Radiation measuring devices and the human bodies are complicated targets.

# Evolution of Quantities

**Protection Quantities**

Dose Equivalent → Effective Dose Equivalent → **Effective Dose**

**Operational Quantities**

MADE → Dose-Equivalent Indexes → **Ambient, Directional and Personal Dose Equivalent→ ICRU Report 95**

# Slab Phantom

- Early work often used a laterally infinite, 30-cm thick slab
  - Generally 4-element compositions, occasionally more
    - Relied at lower energies on *kerma approximation*
  - Computational power dictated the use of one dimension in early years
  - These works still provide valuable insight

# Maximum Dose Equivalent

Operational expression of the "**critical organ**" system of protection.

- Any "**critical organ**" could be protected provided the maximum dose equivalent in the body did not exceed the critical organ dose limit.
- For relatively low-energy neutrons this maximum occurred at depths less than 1 cm in soft tissue.

- **ICRP Publication 21** - neutron fluence-to-MADE conversion coefficients (**NCRP 38**)

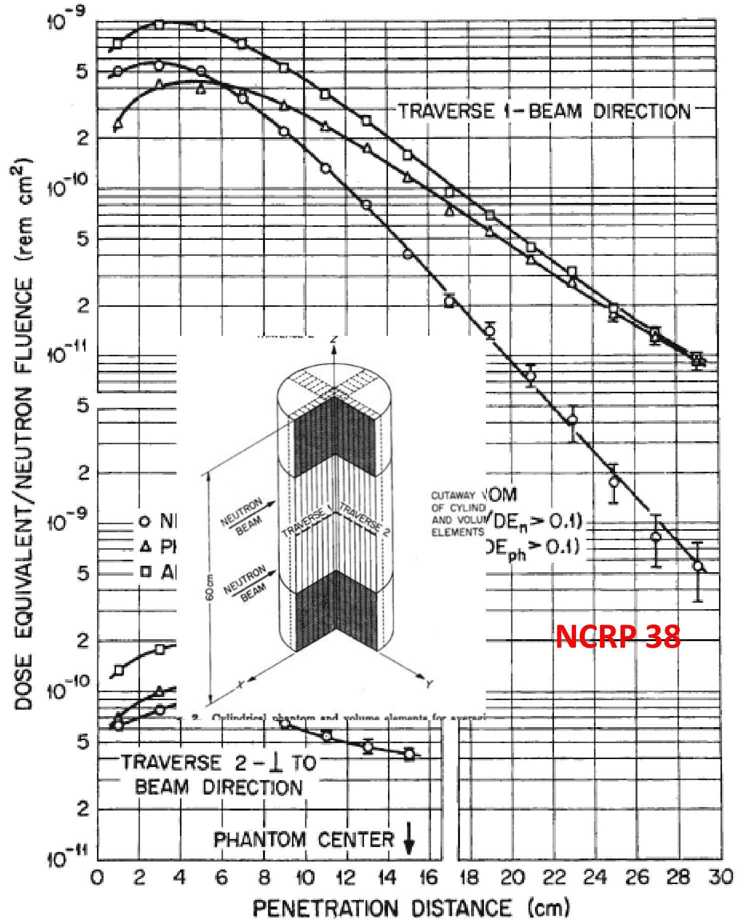



**Fig. 22.** Dose equivalent in central region of the cylindrical phantom. (Neutron energy 10 keV.)

# Non-Additivity (NCRP 38)

10 keV

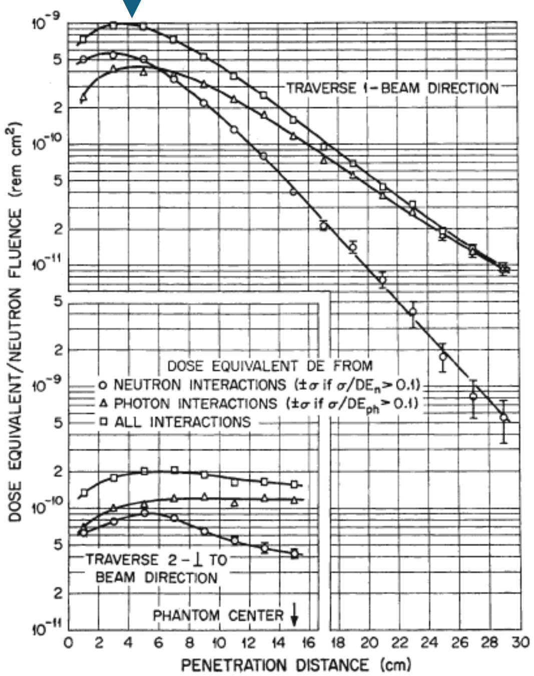



**Fig. 22.** Dose equivalent in central region of the cylindrical phantom. (Neutron energy 10 keV.)

0.1 MeV

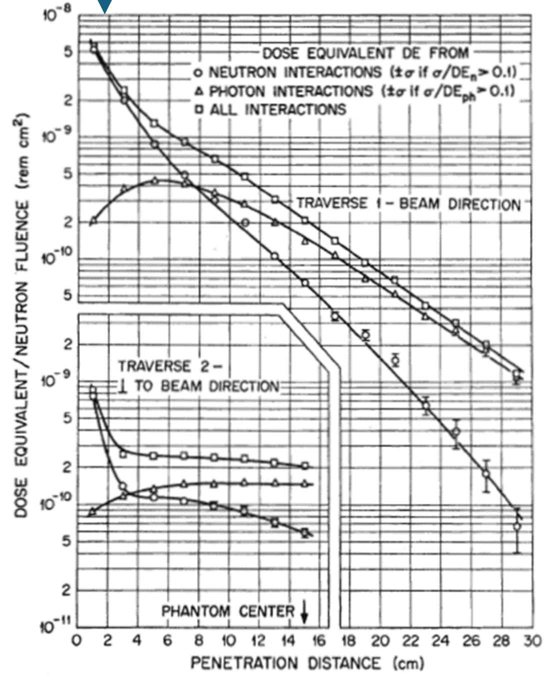



**Fig. 20.** Dose equivalent in central region of the cylindrical phantom. (Neutron energy 0.1 MeV.)

10 MeV

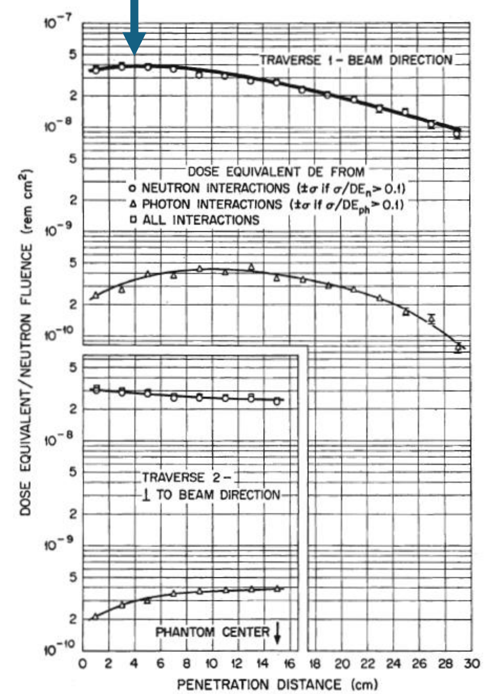



**Fig. 8.** Dose equivalent in central region of the cylindrical phantom. (Neutron energy 10 MeV.)

**ANSI/ANS 6.1.1-1977**

# Dose Equivalent Indexes

ICRU spherical phantom introduced to standardize the calculation of conversion coefficients (**ICRU 25**)

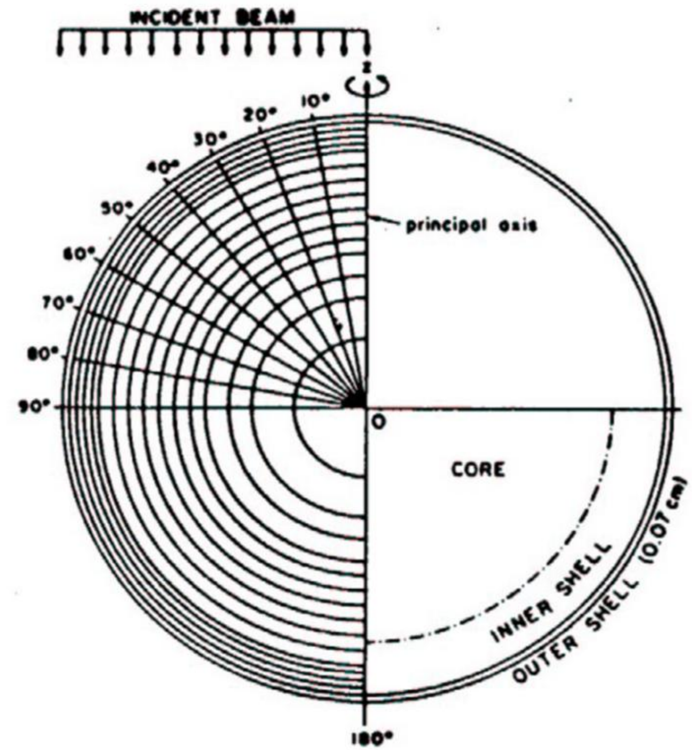
MADE was computed in the sphere and defined as dose equivalent indexes

Deep and shallow dose equivalent indexes

Outer 0.07 mm outer shell ignored

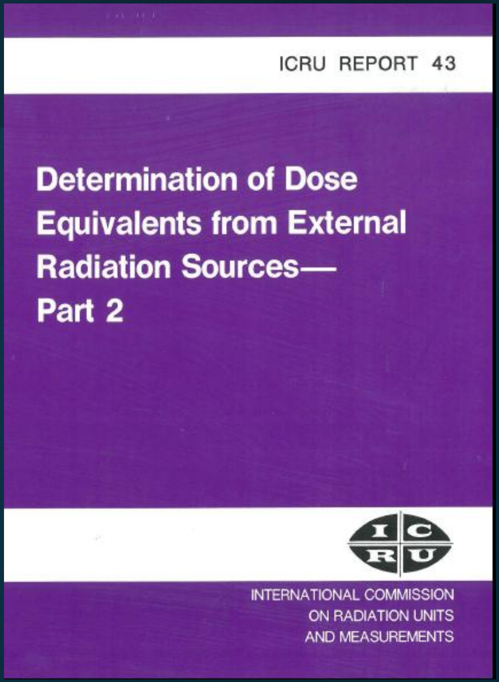
Short-lived as a quantity

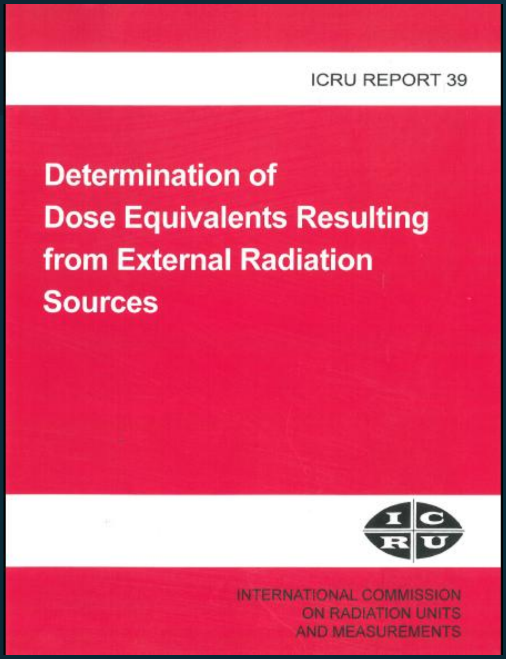
**Non-Additive**




1.0 g/cm$^3$
H - 10.1%
C - 11.1%
N - 2.6%
O - 76.2%

# Operational quantities moved forward and I moved into computational dosimetry



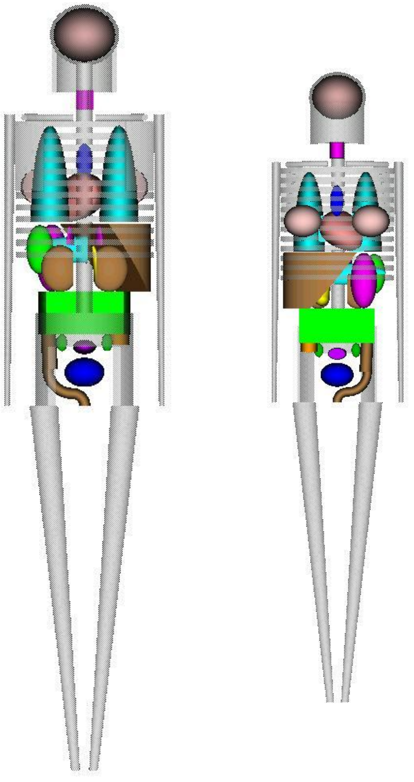

# Protection Quantities – Dose Quantities specified in the human body by the ICRP

A Quick Look

# Effective Dose Equivalent, $H_E$

$$H_T = \overline{Q} D_T = \frac{1}{m_T} \int_{m_T} \int_{L} Q(L) \left( \frac{dD}{dL} \right) dL$$

- Introduced in ICRP Publication 26 (1977)
- First defined for internal dosimetry, then later recommended for external dosimetry
- Has two weighting components
  - Organ/tissue weighting factor $w_T$
  - Quality factor, Q
- ANSI/AND 6.1.1-1991



# Effective Dose (ICRP 60)

- In 1990, the ICRP issued defined a new limiting quantity, the ***effective dose***, *E*:

$$E = \sum_{\mathrm{T}} w_{\mathrm{T}} \sum_{\mathrm{R}} H_{\mathrm{T,R}}$$

- $H_{\mathrm{T,R}}$ is the Equivalent Dose to an organ or tissue T:

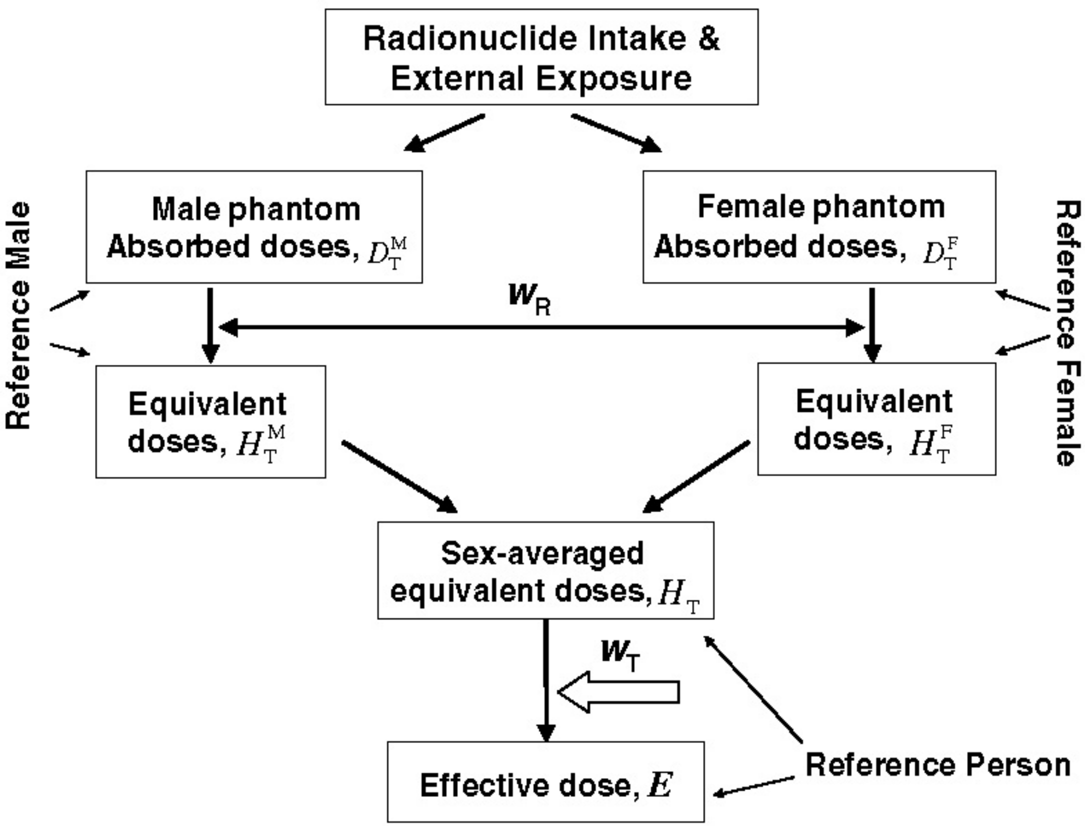
$$H_{\mathrm{T,R}} = D_{\mathrm{T,R}} \times w_{\mathrm{R}}$$

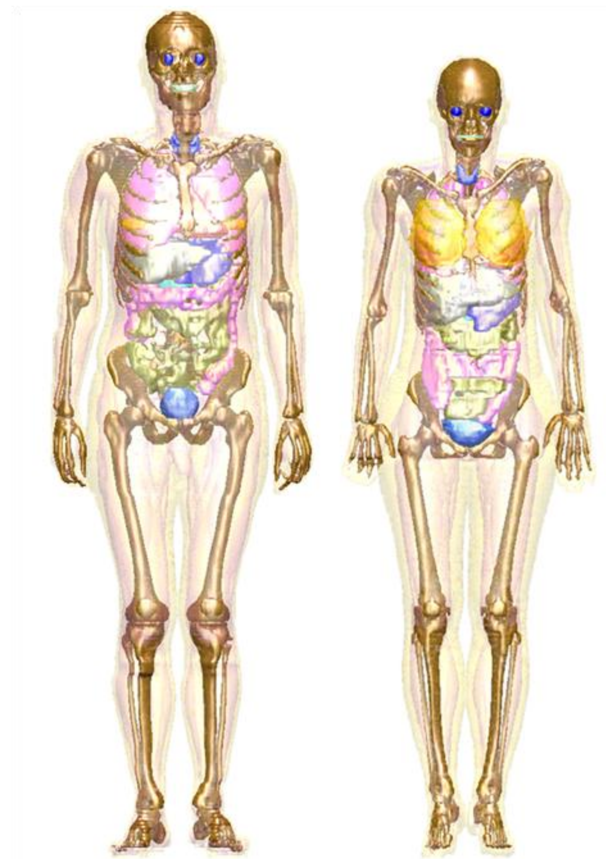
- For neutrons, the organ absorbed dose is the sum of the neutron absorbed dose and the neutron-induced gamma-ray dose in the body.
- The absorbed dose is averaged over the organ or tissue.

# ICRP 103 changed the Tissue Weighting Factors

| Tissue/Organ | ICRP 26 | ICRP 60 | ICRP 103 |
|---|---|---|---|
| Gonads | 0.25 | 0.20 | 0.08 |
| Bone marrow (red) | 0.12 | 0.12 | 0.12 |
| Colon | | 0.12 | 0.12 |
| Lungs | 0.12 | 0.12 | 0.12 |
| Stomach | | 0.12 | 0.12 |
| Bladder | | 0.05 | 0.04 |
| Breast | 0.15 | 0.05 | 0.12 |
| Liver | | 0.05 | 0.04 |
| Esophagus | | 0.05 | 0.04 |
| Thyroid | 0.03 | 0.05 | 0.04 |
| Skin | | 0.01 | 0.01 |
| Bone surface | 0.03 | 0.01 | 0.01 |
| Remainder | 0.3 | 0.05 | 0.12 |
| Brain | | | 0.01 |
| Salivary Glands | | | 0.01 |

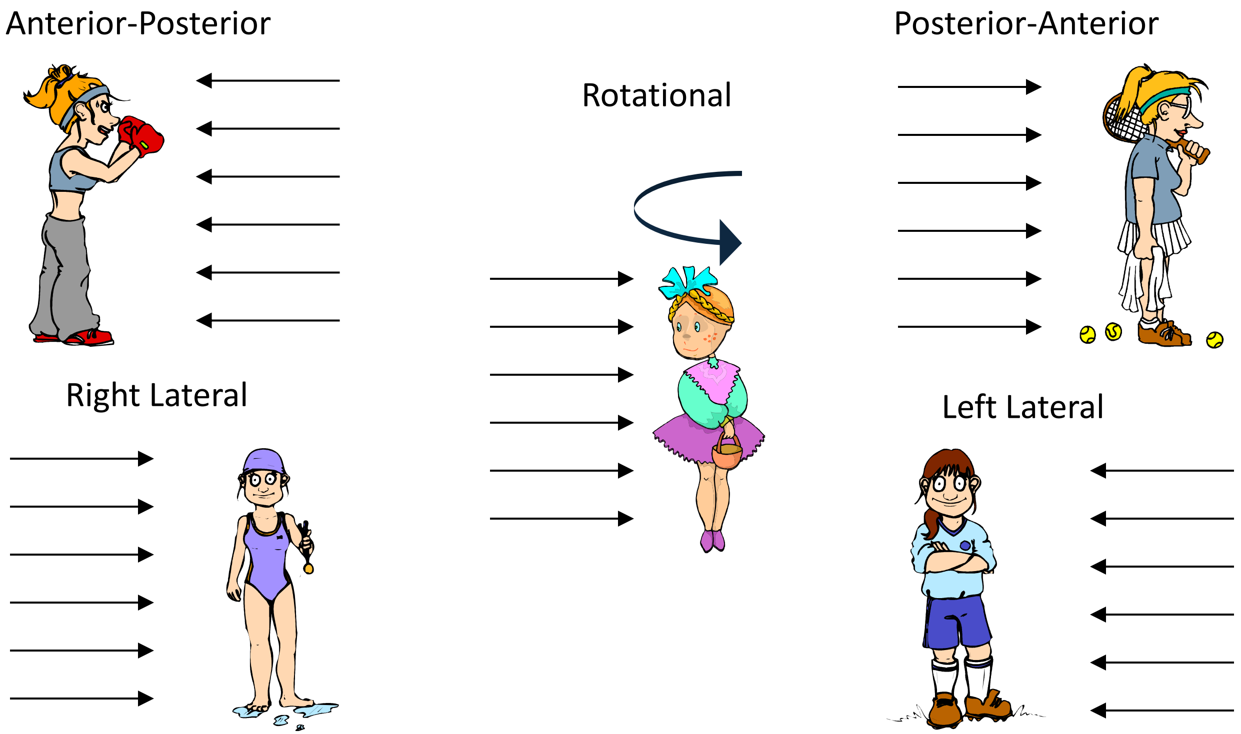
# ICRP 103 Effective Dose



ICRP 110

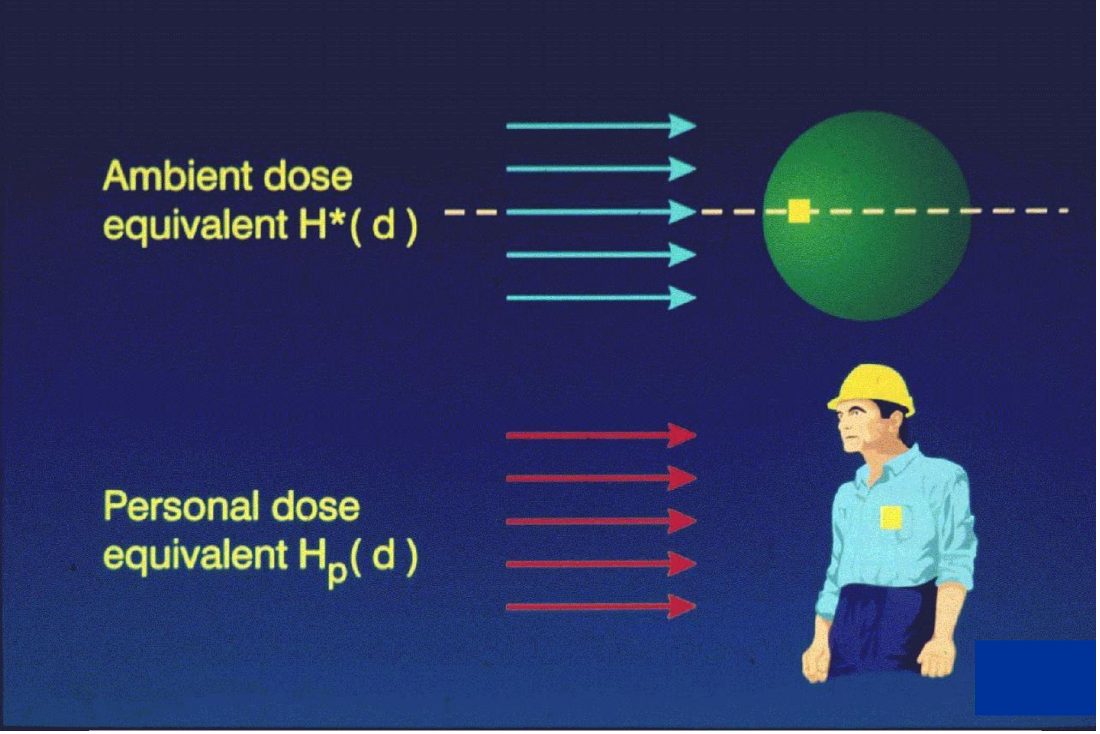
# Irradiation Geometries for Effective Dose

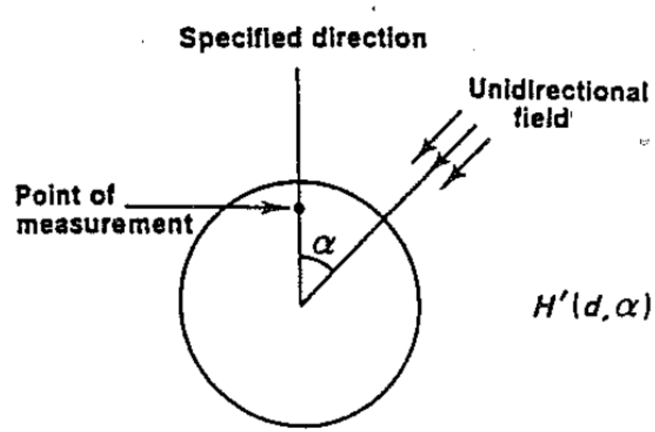


# Operational Quantities

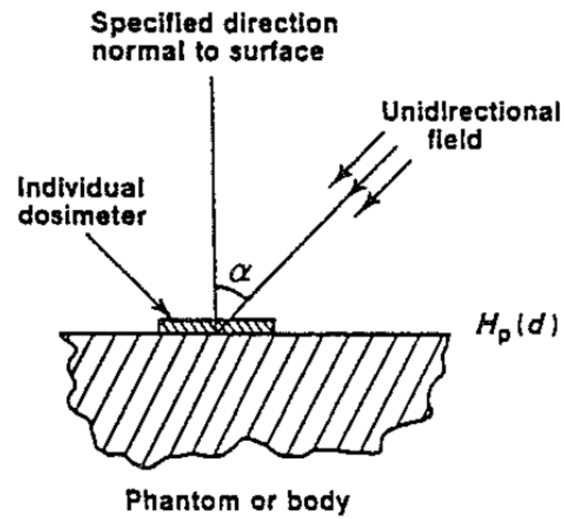
- Used to provide a reasonable estimate of the protection quantities to assess/demonstrate compliance with the limits
- Ambient Dose Equivalent, H*(d)
- Directional Dose Equivalent, $H'(d,\alpha)$
- Personal Dose Equivalent, $H_p(d,\alpha)$
- **Measurable (supposedly?)**
- **Additive**

- **ICRU Report 39**, Determination of Dose Equivalents Resulting from External Radiation Sources
- **ICRU Report 43**, Determination of Dose Equivalents from External Radiation Sources–Part II
- **ICRU Report 47**, Measurement of Dose Equivalents from External Photon and Electron Radiations
- **ICRU Report 51**, Quantities and Units in Radiation Protection Dosimetry



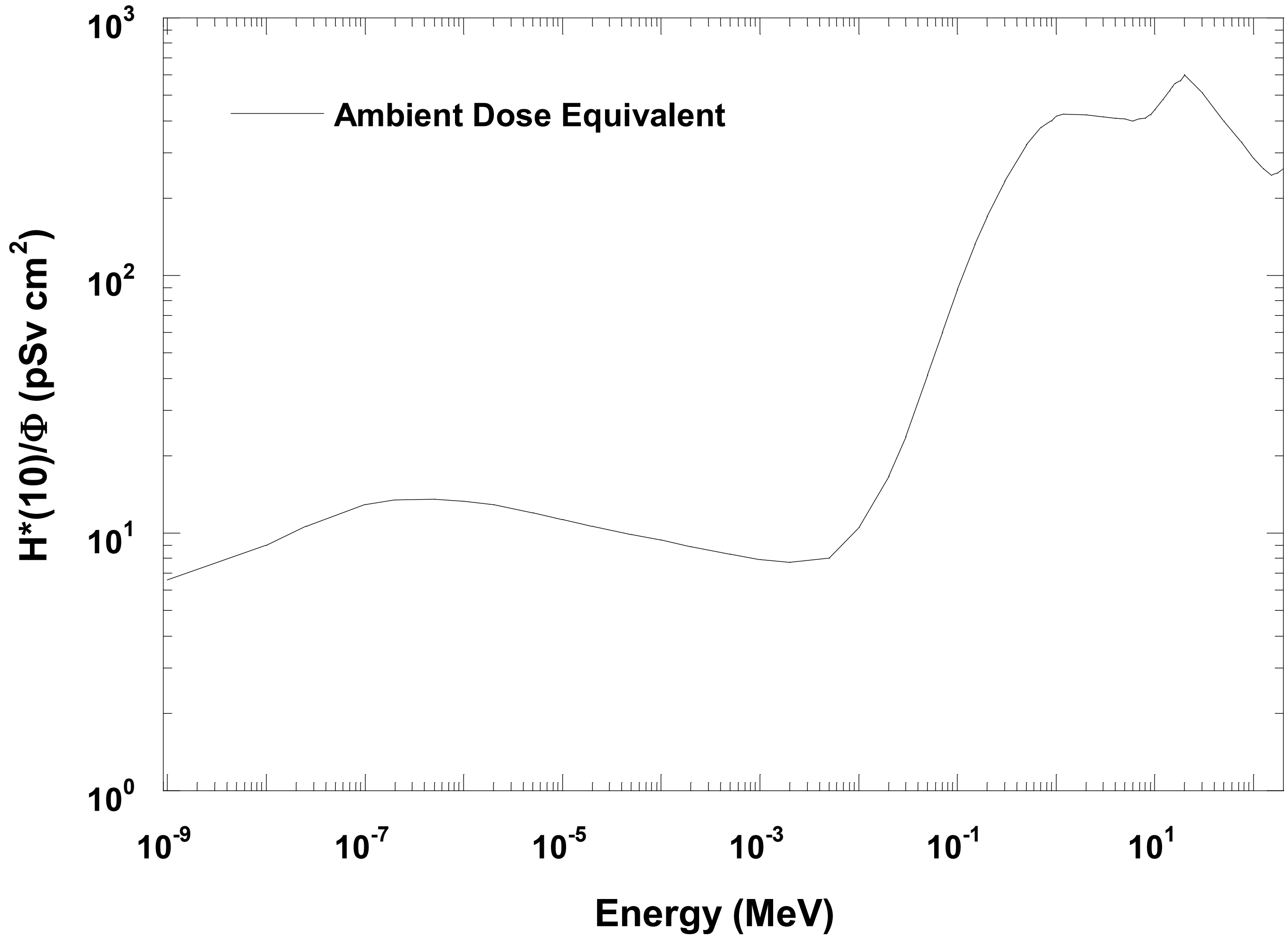





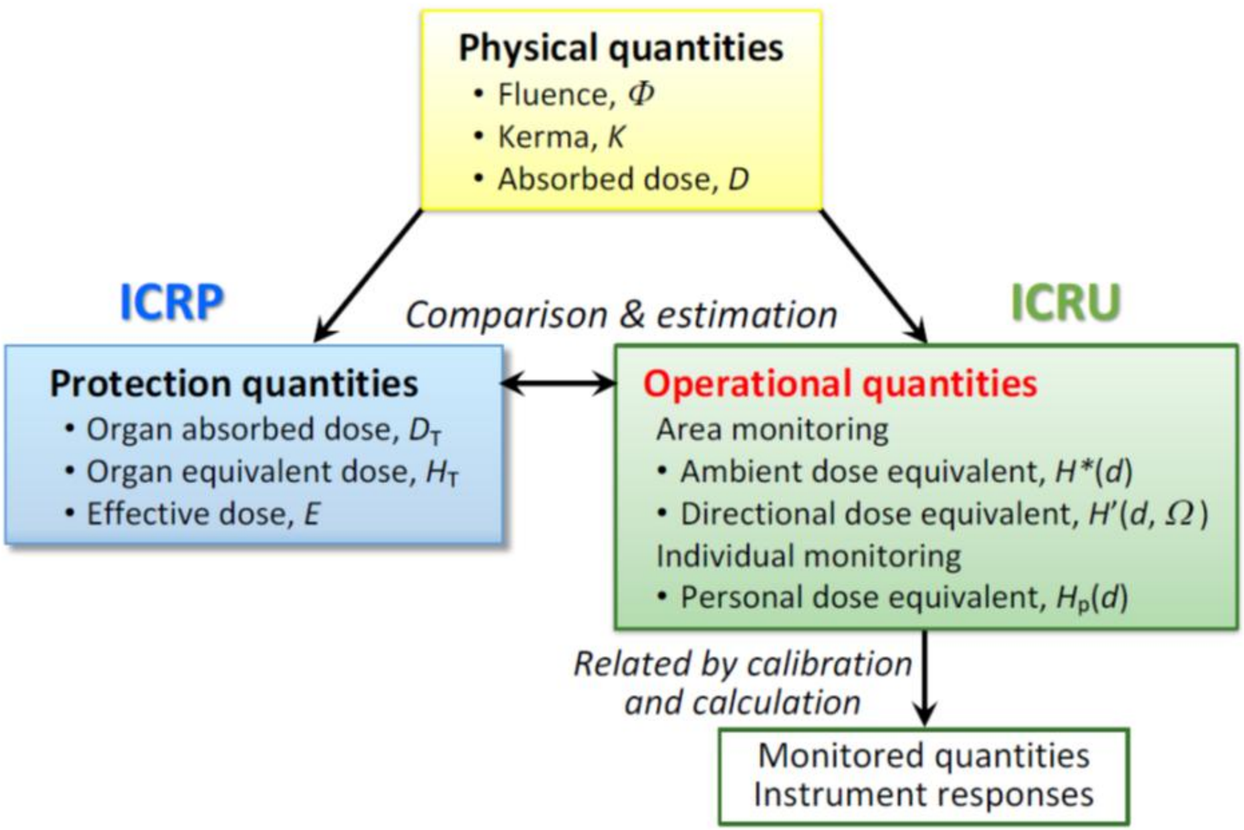



# Operational Quantities

# ICPR 74/ICRU 57 Neutrons Fluence-to-Ambient Dose Equivalent Conversion Coefficients

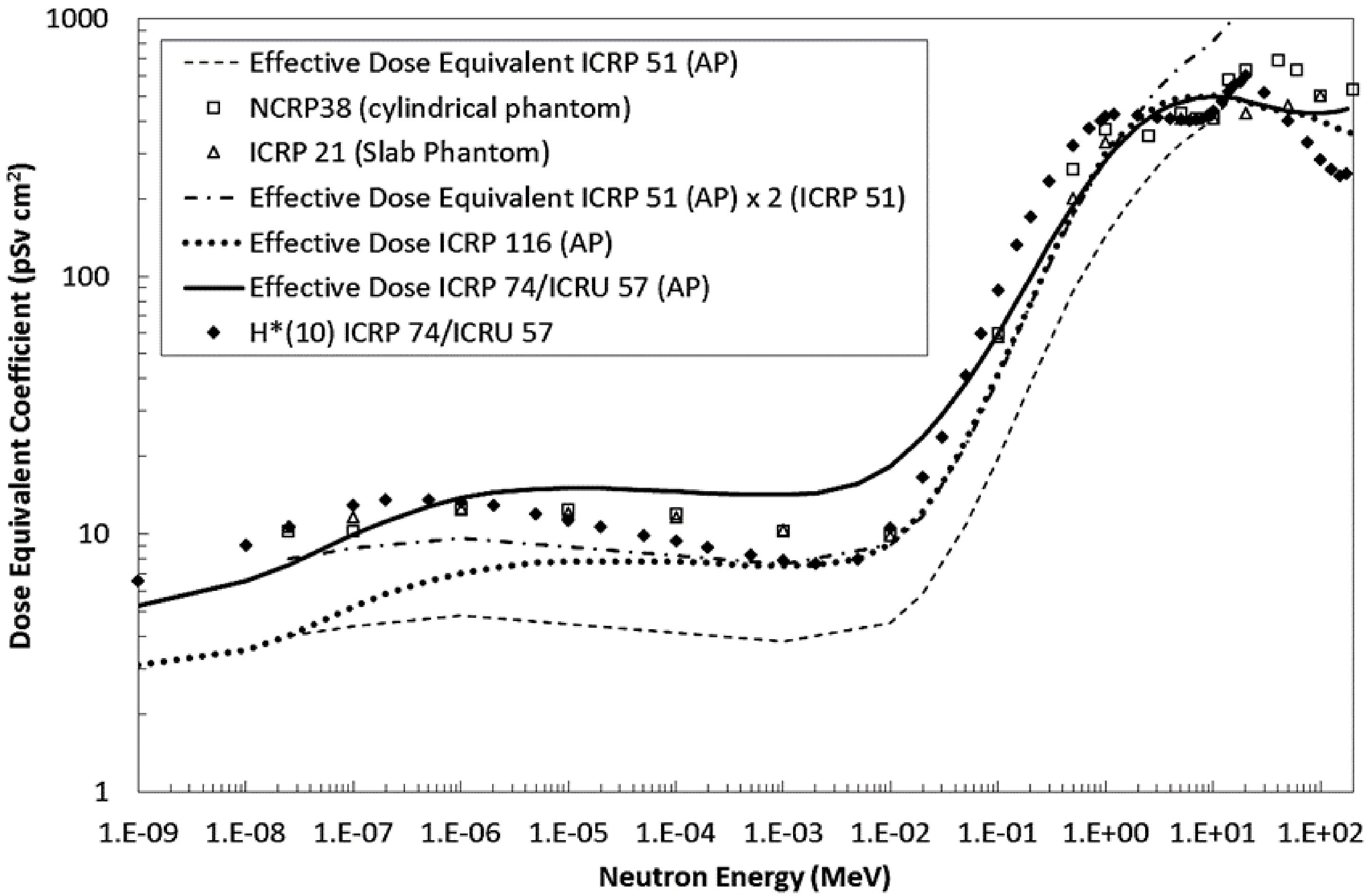


# Relationships



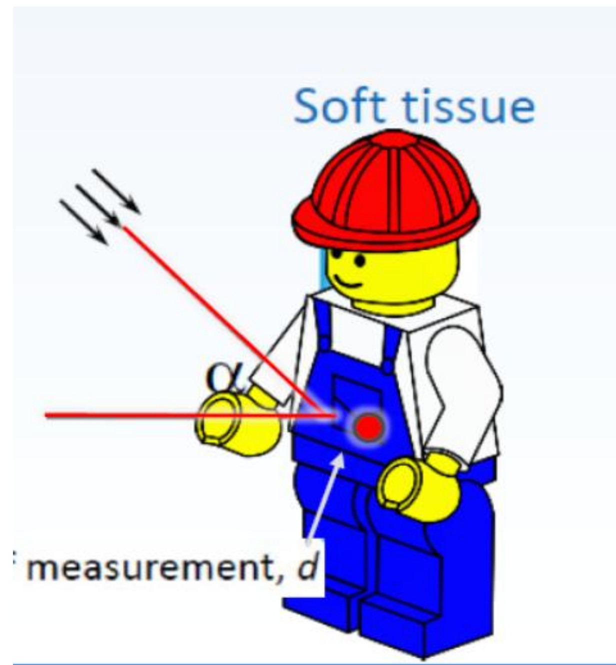

Pick out the Reference Man?

# Some Neutron DCCs (in Advanced Radiation Protection Dosimetry)

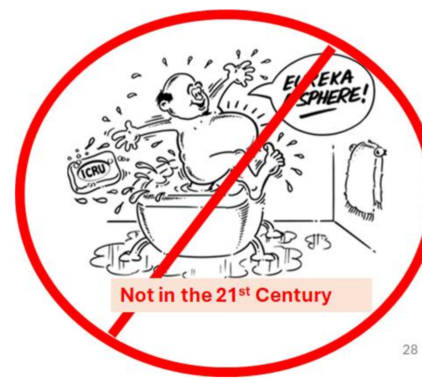


# Limitations of the ICRU Report 39/51 Operational Quantities - an example

Personal dose equivalent *H*p(*d*), was defined at depth *d* in the human body, but the conversion coefficients are calculated in simple geometrical bodies of slabs, cylinders and rods



# A Really Quick Look at ICRU 95

# Relation of protection quantities and recommended operational quantities

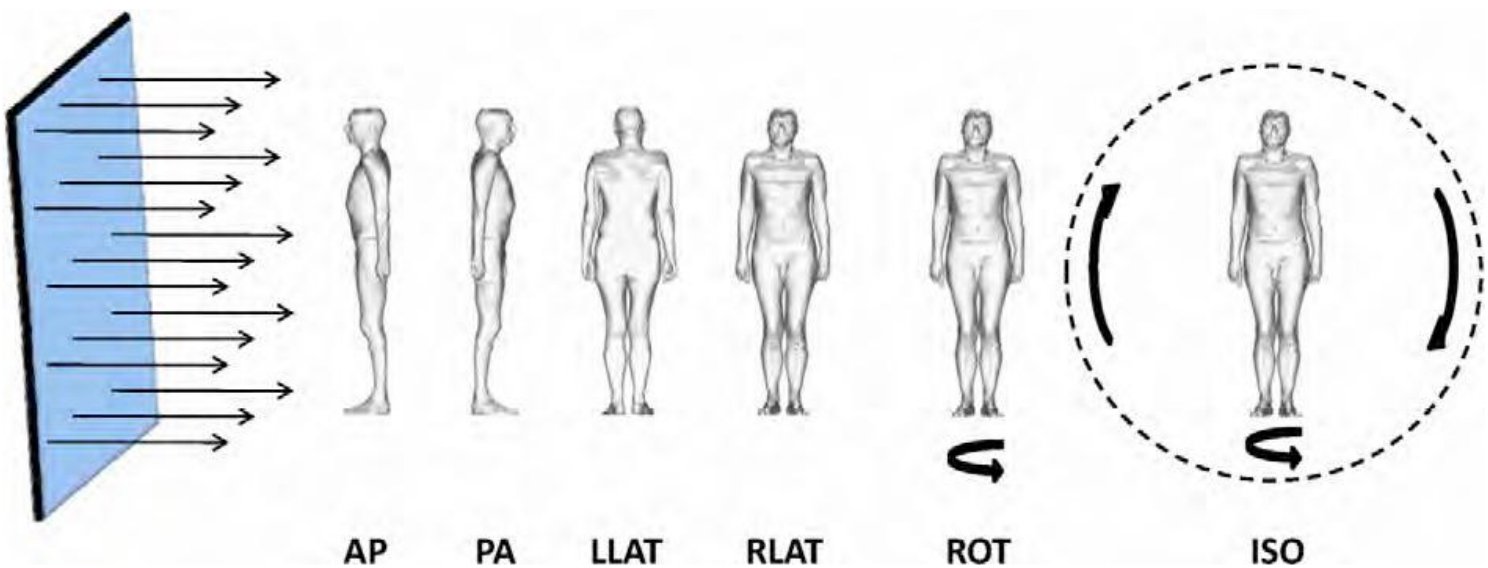
| | | Whole body | Lens of the eye | Local skin |
|---|---|---|---|---|
| Protection quantity | | Effective dose<br>$E$ | Equivalent dose in the lens of the eye<br>$H_{T\ lens}$ | Equivalent dose in local skin<br>$H_{T\ local\ skin}$ |
| Operational Quantity | Area monitoring | Ambient dose<br>$H^*$ | Directional absorbed dose in the lens of the eye<br>$D'_{lens}(\Omega)$ | Directional absorbed dose in local skin<br>$D'_{local\ skin}(\Omega)$ |
| | Individual monitoring | Personal dose<br>$H_p$ | Personal absorbed dose in the lens of the eye<br>$D_{p,lens}$ | Personal absorbed dose in local skin<br>$D_{p\ local\ skin}$ |

# Summary of Phantoms

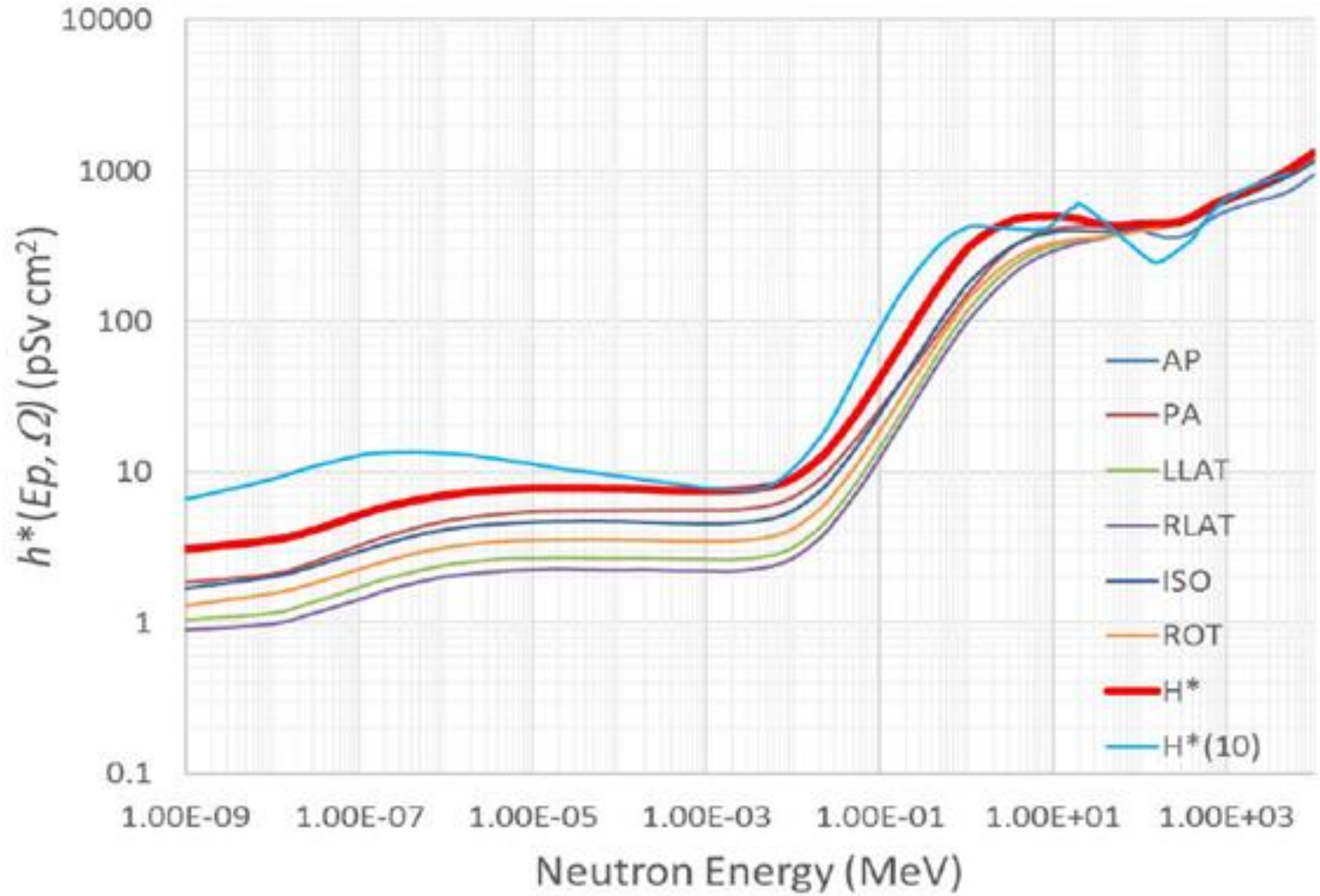
| | **Whole Body** | **Lens of Eye** | **Local Skin** |
|---|---|---|---|
| Protection quantity | ICRP/ICRU adult reference phantoms | Stylized eye model embedded in stylized whole-body phantom | 100x100x100 $mm^{3}$, Skin tissue phantom |
| Operational quantities: Area monitoring | ICRP/ICRU adult reference phantoms | Stylized eye model embedded in stylized whole-body phantom | Slab phantom: 300x300x150 $mm^3$ ICRU tissue with 2 mm skin |
| Individual monitoring | ICRP/ICRU adult reference phantoms | Stylized eye model embedded in stylized whole-body phantom | Slab phantom: 300x300x150 $mm^3$ ICRU tissue, with 2 mm skin<br><br>Pillar phantom: Ø73x·300 $mm^3$ ICRU tissue, with 2 mm ICRP skin<br><br>Rod phantom: Ø19x300 $mm^3$ ICRU tissue, with 2 mm ICRP skin |

# Ambient Dose

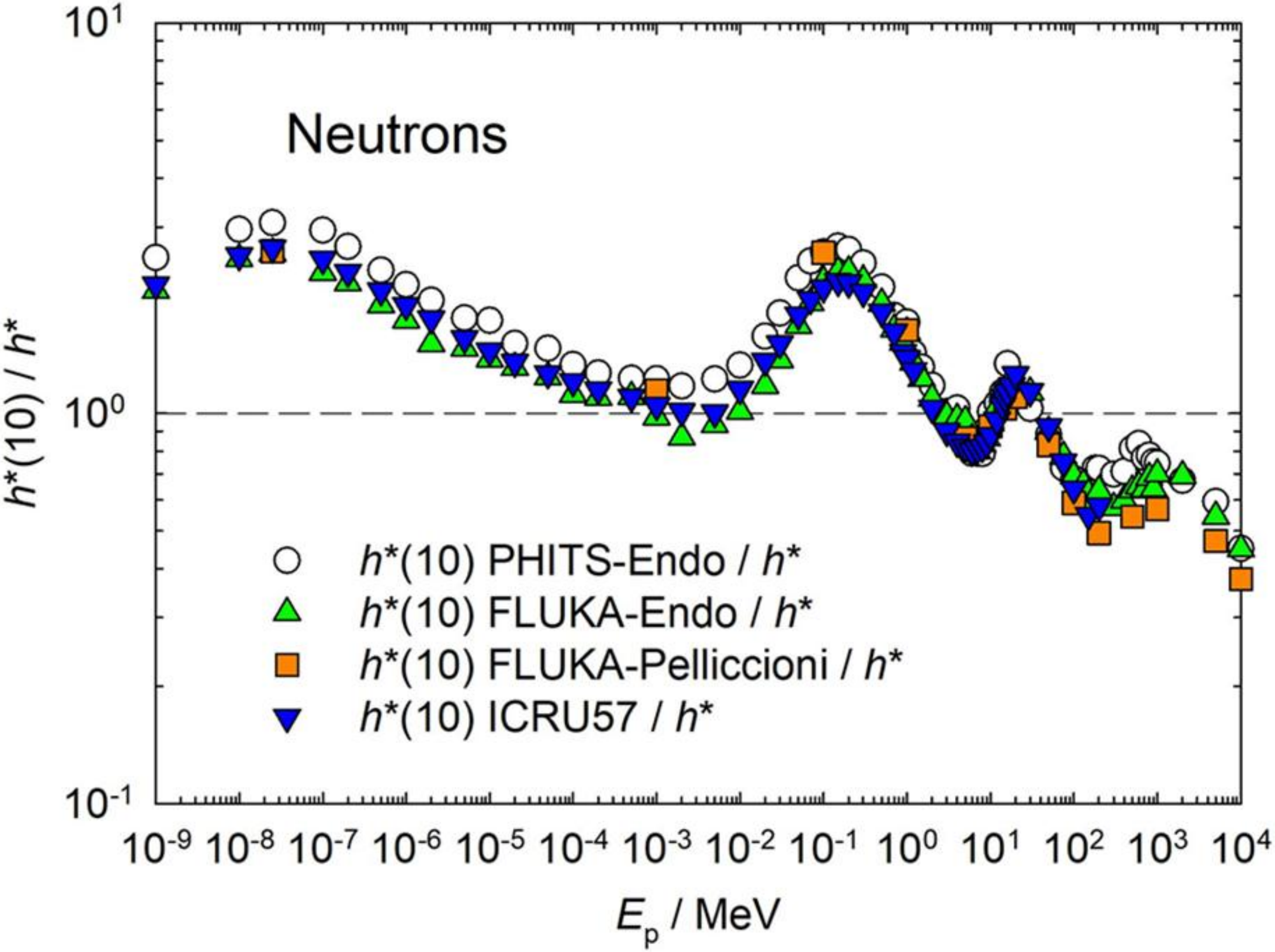
The *ambient dose*, $H^*$, at a point in a radiation field, is the product of the particle fluence at that point, $\Phi$, and the conversion coefficient $h^*_{E\text{max}}$ relating particle fluence to the maximum value of effective dose, $E_{\text{max}}$ for various irradiation conditions



# H*

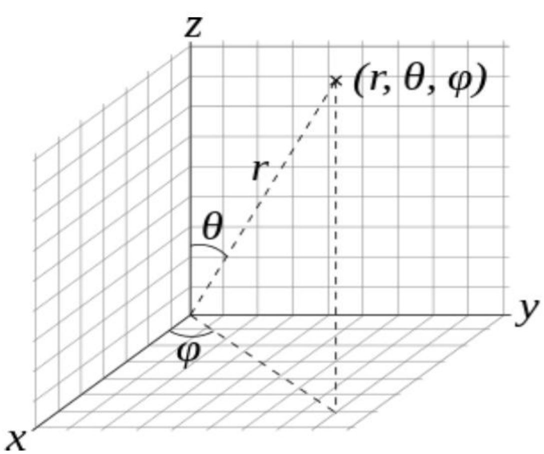


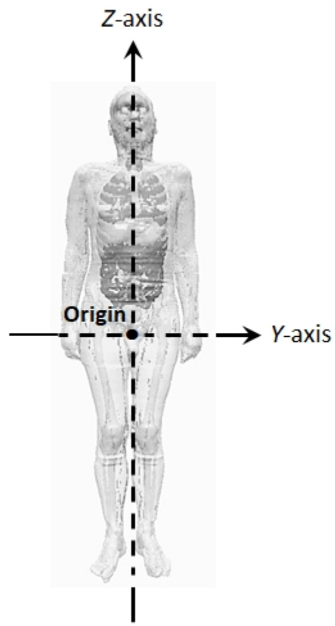
10000
1000
100
10
1
0.1
h*(Ep, Ω) (pSv cm²)
1.00E-09
1.00E-07
1.00E-05
1.00E-03
1.00E-01
1.00E+01
1.00E+03
Neutron Energy (MeV)
AP
PA
LLAT
RLAT
ISO
ROT
H*
H*(10)

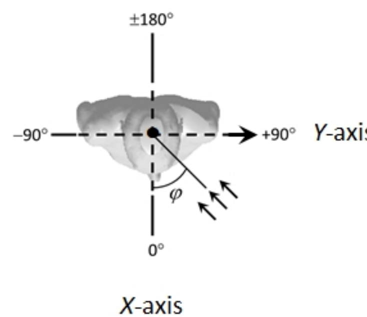

Neutrons
h*(10) / h*
E_p / MeV
h*(10) PHITS-Endo / h*
h*(10) FLUKA-Endo / h*
h*(10) FLUKA-Pelliccioni / h*
h*(10) ICRU57 / h*
10^1
10^0
10^-1
10^-9
10^-8
10^-7
10^-6
10^-5
10^-4
10^-3
10^-2
10^-1
10^0
10^1
10^2
10^3
10^4

# Personal Dose

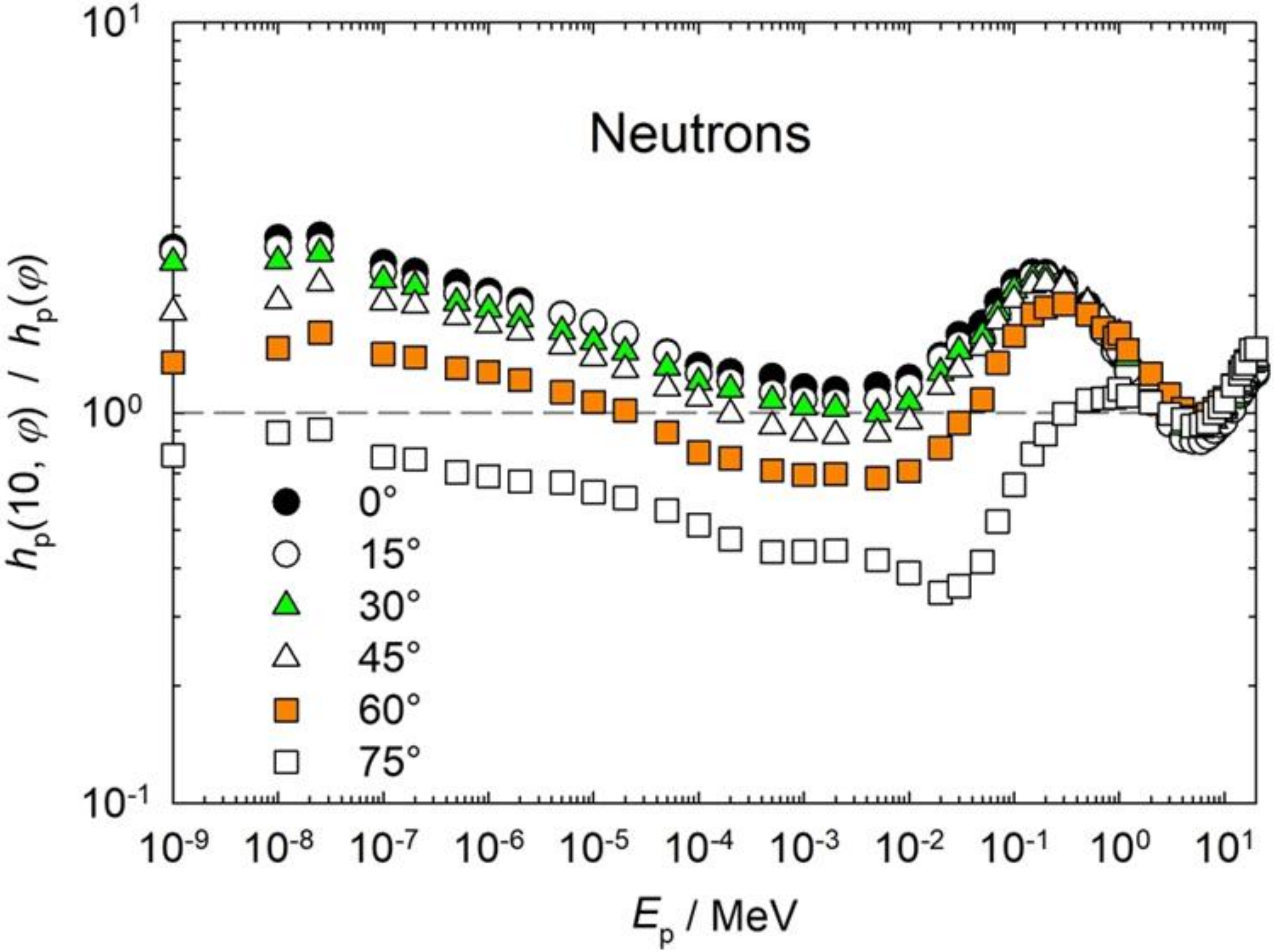
The *personal dose* $H_p$ at a point on the body is the product of the particle fluence incident at that point, $\Phi$, and the conversion coefficient $h_p$ relating particle fluence to the value of effective dose $E$



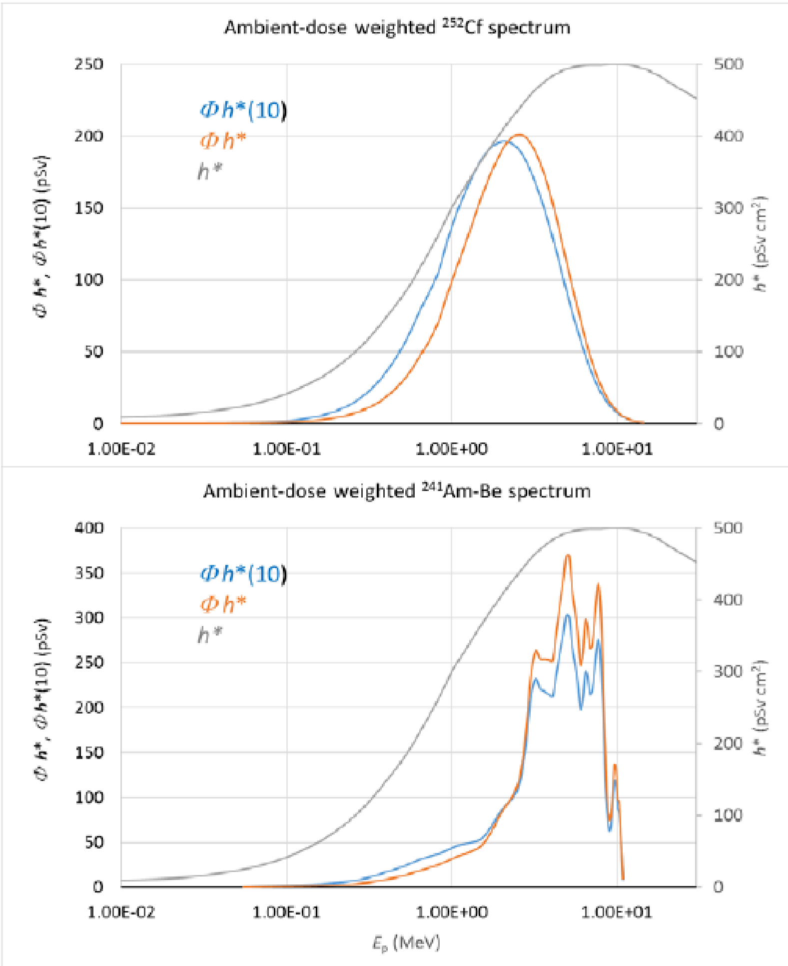




For a given $\Omega$, other than those for 0°, 180°, ROT, ISO, IS-ISO, and SS-ISO, the conversion coefficient taken is that of effective dose as the average value for radiation incident from left and right


Neutrons
$h_p(10, \varphi)$ / $h_p(\varphi)$
$E_p$ / MeV
0°
15°
30°
45°
60°
75°
$10^{1}$
$10^{0}$
$10^{-1}$
$10^{-9}$ $10^{-8}$ $10^{-7}$ $10^{-6}$ $10^{-5}$ $10^{-4}$ $10^{-3}$ $10^{-2}$ $10^{-1}$ $10^{0}$ $10^{1}$

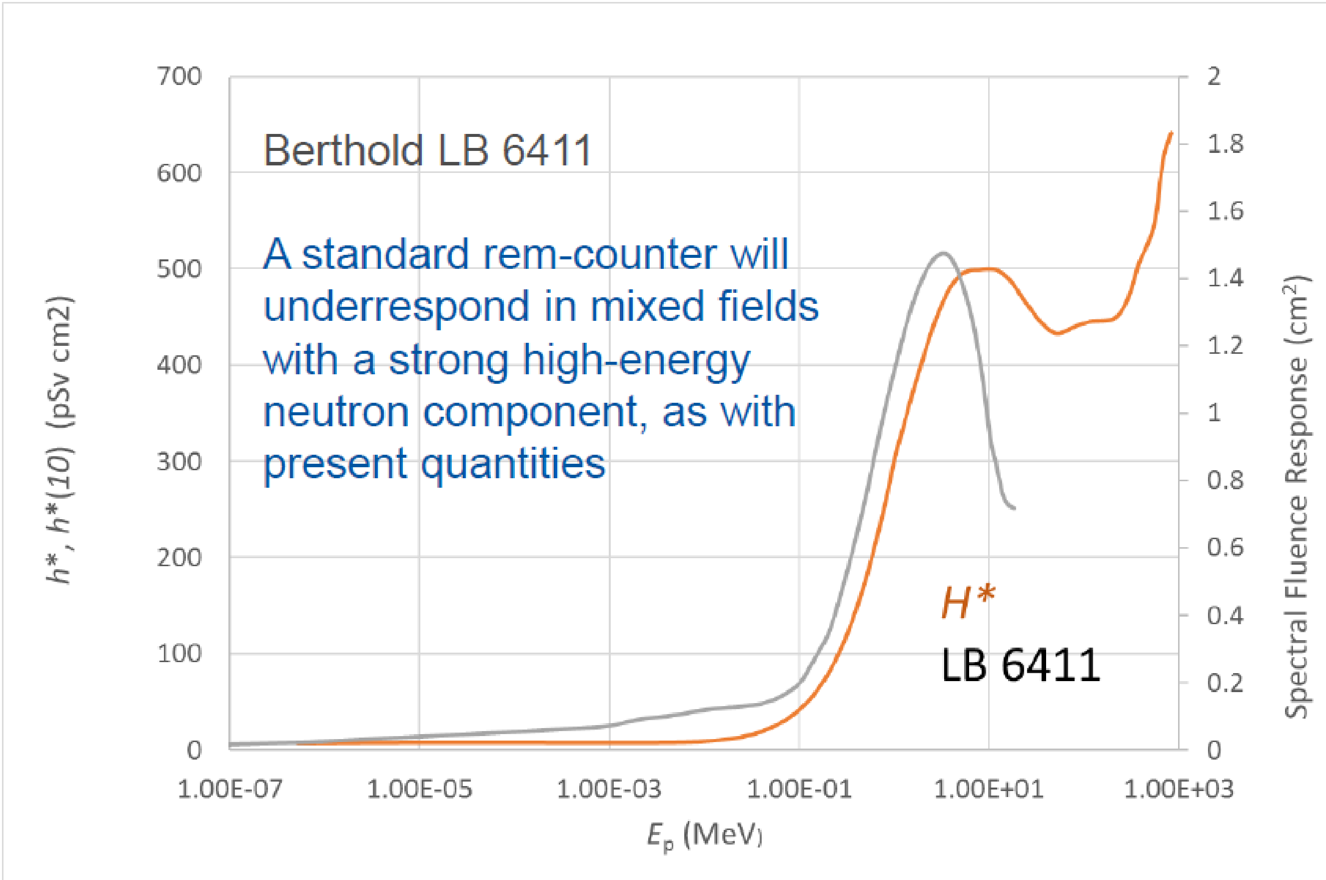
# Changes to neutron reference fields



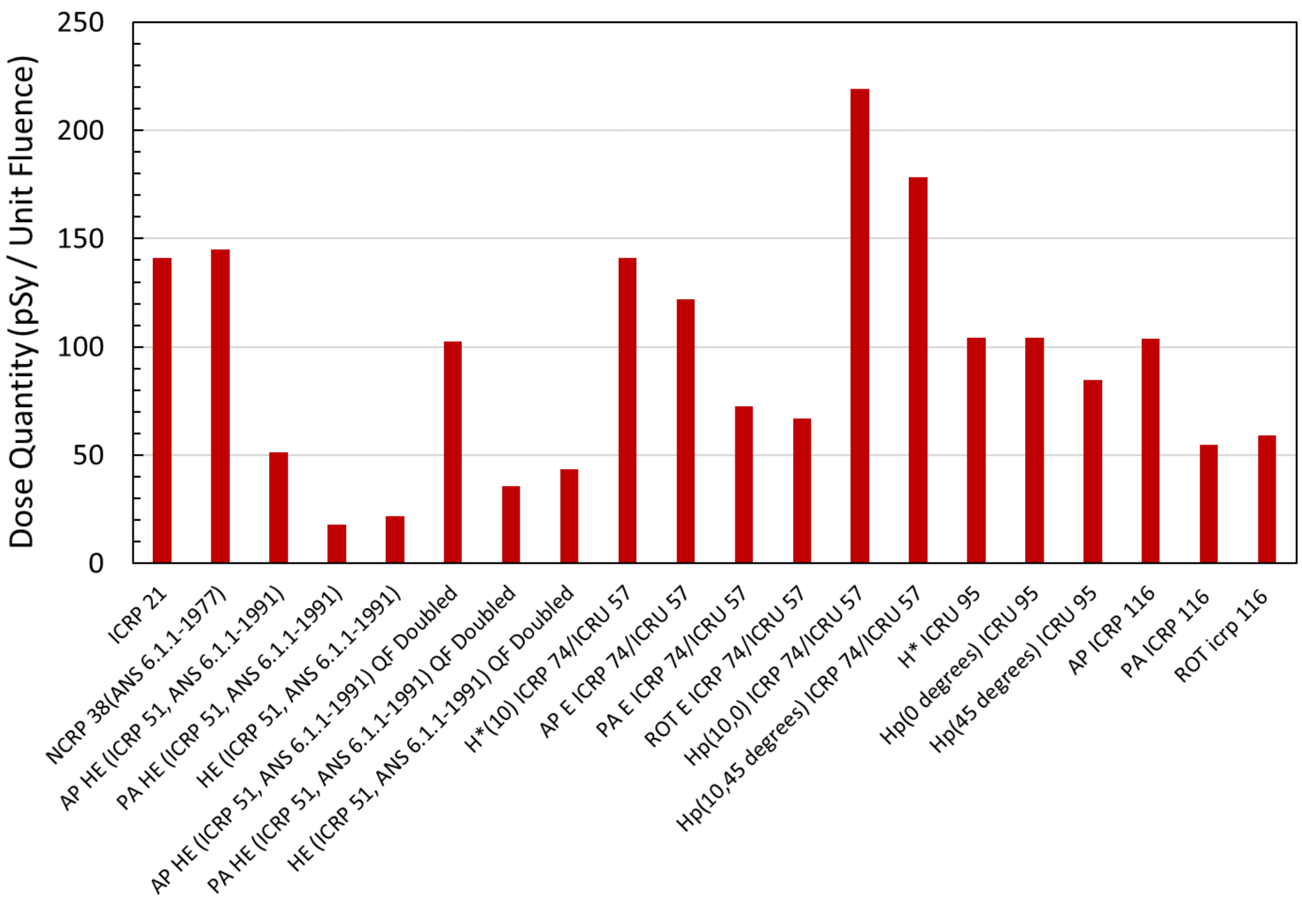

Spectrum-weighted conversion coefficients (pSv cm$^2$)

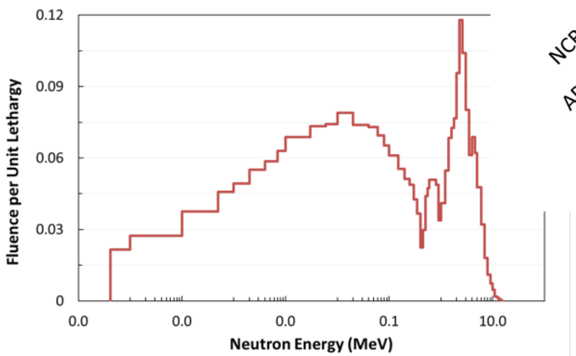
| | ICRU 57 | ICRU RC 26 |
|---|---|---|
| $^{252}$Cf | 385 | 351 |
| $^{252}$Cf ($D_2O$) | 110 | 95 |
| $^{241}$Am-Be | 392 | 427 |

# Response of neutron monitors

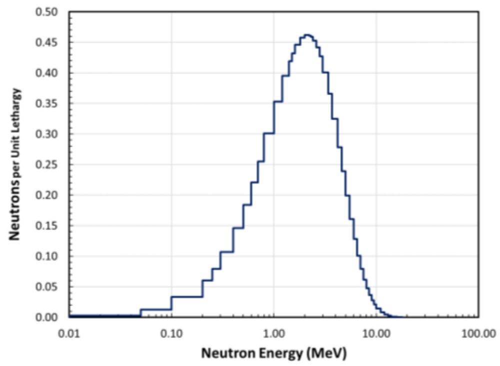


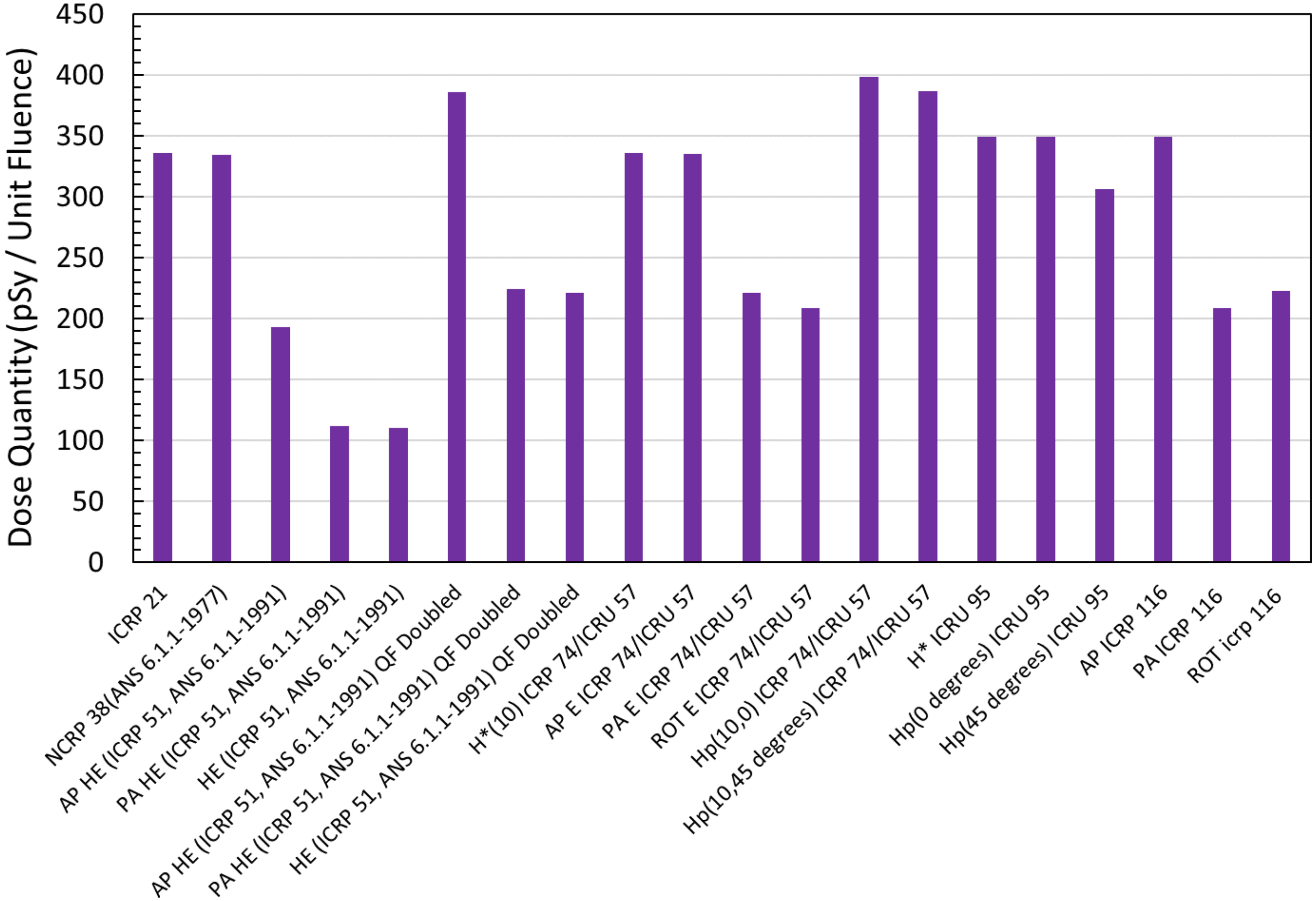
# Heavy Water Moderated Cf-252 (ISO 8529)



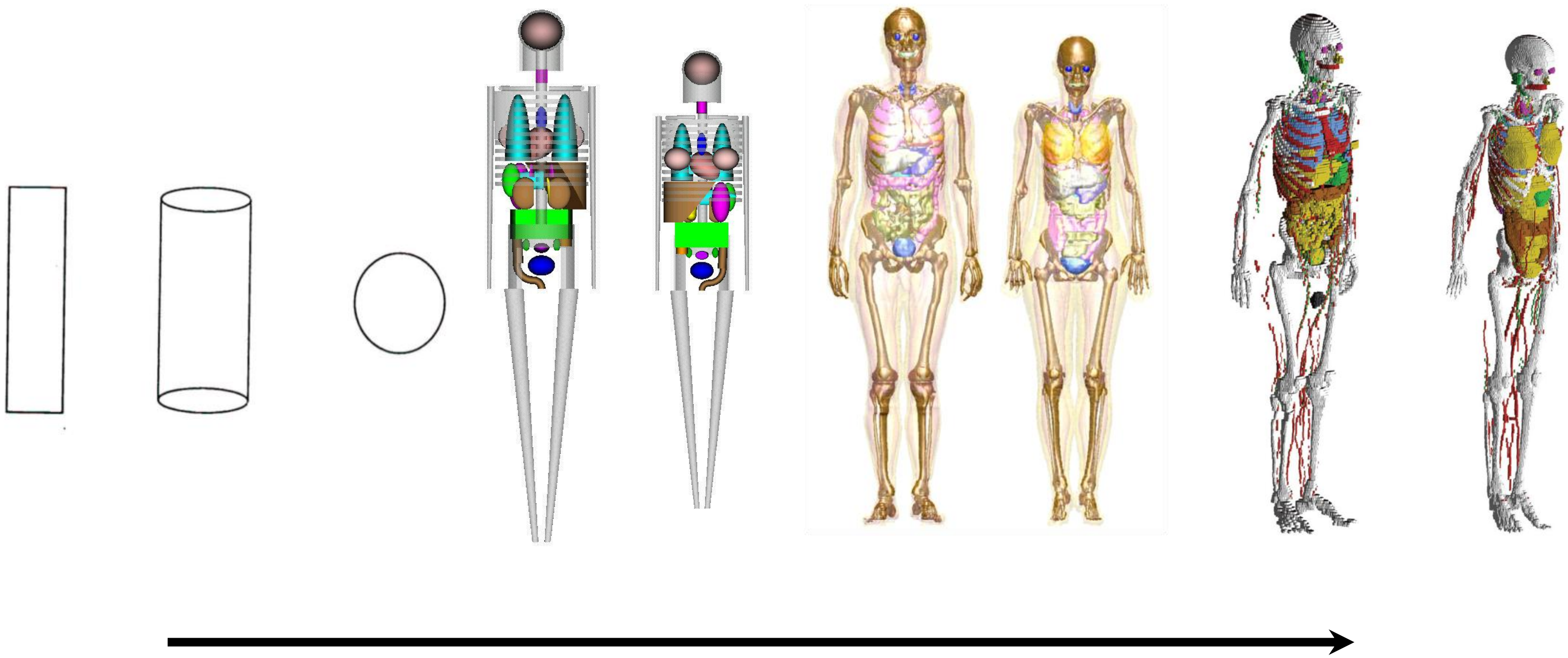



# Unmoderated Cf-252 (ISO 8529)



# Your Body as a Target – Phantom Evolution Continues



**Time or Computer Capabilities**

# Is anyone using ANSI/ANS 6.1.1-2020?

**“The purpose of computing is insight, not numbers.”**

- “Thus computing is, or at least should be, intimately bound up with both the source of the problem and the use that is going to be made of the answers --- it is not a step to be taken in isolation from reality.”

R. W. Hamming, Numerical Methods for Scientists and Engineers, 2nd Edition